STUDIES FROM THE PSYCHOLOGICAL LABORATORY OF THE UNIVERSITY OF MICHIGAN.

COMMUNICATED BY W. B. PILLSBURY.

IX. EYE-MOVEMENTS.

By BERNICE BARNES.

Comparatively little work has been done on the subject of eye-movements, although its psychological value has been much disputed.

Two important laws of movement have been formulated, the law of preference of the primary position, or Listing's Law, and the law of constant orientation, known as Donder's Law. These laws are variously stated. Helmholtz[1] phrases Donder's Law thus: "Given the position of the line of regard in relation to the head, and you have given with it a definite and invariable torsion value." Meinong[2] expresses it in the same way. Wundt says, "The orientation of the eye for any position of the line of vision is constant, no matter by what path the line of vision may have been brought to this position." That is to say, if you set out with the lines of regard parallel, you may move from any position you like, to any other position you like in the field of regard, and the orientation of the eye in this second position will always be the same, whether the eye is moved directly from the first position to the second, or in the most roundabout way.

Listing's Law implies not only a parallel position of the lines of regard, but also the primary position of the eyes as a starting-point. Helmholtz says: "If the line of regard travel from the primary to any other position, the torsion of the eyeball in the second position is the same as if the eye had turned about a fixed axis at right angles to the first and second directions of the line of regard. Hering states it more clearly and Meinong uses about the same words: "In movements from the primary position, the line of vision can describe a plane path, or the regard travel along a straight line, in any direction whatever, without there being any torsion of the eye at all about the line

[1] Physiologische Optik, p. 619.

[2] Ueber Raddrehung, Rollung u. Aberration, Zeitschrift für Psychologie and Physiologie, Vol. XVII, pp. 161 ff.

of vision,'' in other words, the eye can be turned in all directions about a fixed axis, at right angles to the line of vision, without causing torsion about the line of vision. Wundt's[1] statement is somewhat more complicated, ''All movements from the primary position take place around fixed axes, each of which cuts the plane described by the line of vision in turning, at right angles in the point of rotation, and all of which lie in a single plane, cutting the primary position of the line of vision at right angles in the point of rotation.'' That is to say, if you set out with the lines of regard parallel in the primary position, you may move to any point of the field of regard that you like, in the vertical, horizontal or oblique direction, and your eye will undergo no torsion at all.

As to the psychological value of these laws, Helmholtz looks upon Donder's Law as a guarantee that resting objects in the field of vision are recognized as such, when the eye itself has been moved. Hering estimates Listing's Law thus, ''It brings the space perception (localization) of the moved eye into the greatest possible unison with the localizations of the resting eyes, so that the displacements of the mental images harmonize with the intended movements of regard, while it also assures in far vision the most perfect possible correspondence of the retinal images of the double eye.''

So much for the statement and significance of these laws. A word of explanation is necessary regarding the terms used. All movements of the eye may be conceived as rotations about one or more of three axes, a sagittal axis, corresponding with the line of sight, which passes directly through the centre of the pupil from front to back; a frontal axis, extending horizontally from left to right, and a vertical axis. Theoretically, all these intersect at right angles in the centre of rotation of the eye. What is known as the primary position, is the position which the eyes assume when the head and body are erect, and the eyes are directed forward to a distant horizon. Any other position is called a secondary position, although Helmholtz often speaks of a tertiary position, in movements from one secondary position to another. The point on which the eyes are fixed when in the primary position is the primary fixation-point, or principle point of regard. The field of vision is the extent of space that can be seen with the eye at rest. The field of regard is the extent of space that can be seen when the eyes are moved.

The method used by Helmholtz and others for determining the validity of the laws of Donders and Listing, and other facts of eye-movement, is the so-called after-image method. A strip

[1] Wundt: Grundzüge d. Phys. Psycho., II, p. 525.

or a cross of red or green paper is put in the centre of a sheet of gray cardboard, which is tacked on a wall space, preferably of neutral gray like the cardboard, although white will do, at such a height that the eyes of the subject, seated at a table some feet distant, may, in the primary position, be fixated on the red paper. Several points are then chosen on the wall about the cardboard, and the distances carefully measured. The eye is then turned from the primary position to these various points, and of course the after-image of the colored slip appears at the point, turned or straight as the case may be, and the amount of turning is measured. This method of experimentation is very crude, for after-images are unstable and illusory things, the best you can make of them, and the results are of necessity very inaccurate, since the person carrying on the experiment holds a slip of paper the size of the red slip, at the point to which the eyes are directed and turns the slip until the subject says that it coincides with the after-image which he sees there. It is evident that the slightest movement of the eyes in this new position will cause considerable shifting of the after-image.

In my experiment I have used a more complicated and elaborate instrument, which insures accurate results. This instrument may be called a torsio-meter, since its main object is to measure the amount of torsion, or rotation about the sagittal axis, which takes place when the eye is moved from one position to another. It consists of an iron arc of 180°, one meter in diameter, mounted on a standard, so that its centre may be directly in front of the eye of the subject, who is seated before it. This arc may be raised or lowered a number of degrees, according to the height of the subject, and the results desired. It may also be swung around from the horizontal to any oblique position or to a vertical position. On this arc is screwed a small, adjustable telescope, having a fine spider web across the eye-piece, which, together with its setting, may be rotated. The amount of rotation is measured by an indicator on a small arc surrounding the telescope, and divided into 50° positive and 50° negative, that is, rotation to the right is measured in negative degrees, since the subject faces the instrument, and rotation toward the left in positive degrees. The large arc on which the telescope is placed is also divided off into degrees. Suppose, now, that the subject is seated in front of the arc, with his head securely adjusted in a head-rest to prevent head movements. A thread is stretched across from end to end of the arc, and the exact centre marked with ink. The ink spot is placed directly in front of the pupil of the eye, and the thread may then be dropped so as to prevent any hindrance from it during the taking of results. The telescope is adjusted at the

middle of the arc, at the zero point, and focused directly on the eye. The experimenter then looks through the telescope, which magnifies sufficiently so that the tiny lines radiating from the pupil through the iris may be clearly distinguished. The eye-piece is now turned so that the spider web rests directly on one of these lines, and then the point shown by the indicator on the arc of the telescope is taken. The results will be less complicated if a distinct line can be covered with the horsehair at the zero-point. I succeeded in doing this with both of my subjects. Then the telescope is moved several degrees to the right or left on the large arc; the eyes move toward the same point, and the lens is turned so that the hair rests on the same line which was chosen at the zero-point. The number of degrees which the indicator moves during this process, will, of course, be the number of degrees of torsion which has taken place during the movement of the eye from one position to the other. Care should be taken that the lines of regard be always parallel, that is, that the eyes should be fixed on an infinitely distant point.

My results differ in some respects from those which have been gained by others, and in other respects they agree. Helmholtz says, "When the movement takes place from the primary position, simple raising or lowering of the eyes without deviation to the side, or simple side movements without raising or sinking, results in no torsion." With the after-image method, this was found to be the case, since the results are only approximate, and the subject is scarcely able to cognize slight deviations from the horizontal or perpendicular, at the distance he is obliged to sit from the wall. With the more accurate instrument, however, the torsion in each case was decidedly noticeable, though slight. (See Table II 1 and 2.) He says further, "In raising or lowering to the same points, the rotation is the more marked, the greater the deviation to the side, and in side movements to the same points, the torsion is more marked the greater the raising or lowering." With this statement my results agree very well. (See Table II.)

In some respects I get the same results as Meinong. For instance, he says, quoting from the two laws of movement, "'In movements from the primary position no torsion takes place. In movements from secondary positions torsion does take place.' These two laws are found to be contradictory. For example: let the eye travel from the primary position diagonally upward to a point at the right of a fixation point at some distance directly above the primary. Another time let it travel from the primary position vertically up to the height of this fixation point, and then horizontally to the right until the above given point is reached. According to the first of the

laws quoted above, the eye, if it moves from the primary position, reaches its goal without torsion as well with a vertical as with a diagonal movement." As a matter of fact, it is found, that torsion, and, moreover, the same amount of torsion, takes place in the diagonal movement as in the vertical and horizontal movements, since the eye is in exactly the same position when the given point is reached, no matter how it has moved to get there. Table IV. (See Donder's Law. Also Table II 11.) The two laws, when taken together, may be reduced to absurdity, since if no torsion took place in turning from the primary to the secondary position, the eye would be in the same position at the secondary point, so far as torsion is concerned, as at the primary point, so that movements from the secondary point would have the same effect as movements from the original primary. Hence no torsion would exist at all. Meinong says, in conclusion to the statement above quoted, "In that secondary position commonly called third position (reached by diagonal movement or vertical + horizontal), the horizontal meridian remains no longer horizontal, the original vertical meridian not vertical, the two positions being twisted in the same manner around the line of vision as axis, so that to such movements, torsion cannot well be denied." Meinong used the after-image method in arriving at this result; but, as I said above, I reached the same conclusion by means of the more accurate instrument, being able by it to measure the exact amount of turning of both movements. (See Table II 11.)

Graefe[1] says, "In raising the line of vision up to the left and sinking the same down to the right, the vertical meridian is inclined toward the left." I find that my results substantiate this also (see Table II 3, 4, 5, 6, 7 and 8.), and would add that in raising the line of vision up to the right and sinking it down to the left, torsion toward the right occurs; in sinking it down to the right and raising it up toward the left, torsion takes place toward the right, and in sinking it down to the left and raising it up to the right, torsion takes place toward the left.

Helmholtz says, "In raised position of the plane of vision, side movements toward the right produce torsion toward the left, and side movements toward the left, torsion toward the right. In a lowered position of the plane of vision, side movements to the right produce also torsion toward the right, and *vice versa*." This also I found to be correct. (See Tables III and IV 9 and 10.)

If I were to sum up my results in a general law of eye move-

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[1] v. Graefe u. Saemisch, Handbuch der Augenheilkunde, Vol. VI.

ment, I should state it thus: "Every movement of the eyes, whether from the primary position to a secondary position, or from a secondary position to any other, is always accompanied by a definite amount of torsion, varying according to the scope of the movement.

Any inaccuracy of results is due to one of two causes. It is impossible to avoid slight movements of the head even when a head-rest is used. The other cause of inaccuracy is what Meinong calls "false torsion," meaning by that, that the eye may turn about the sagittal axis when at rest in the primary position. If it can do this, then the same kind of rotation can take place during movements, or at the second fixation point before the record can be taken, thus detracting from the accuracy of results supposed to be gained by the effect of movement alone. The experiment is very fatiguing, both to the subject and to the experimenter, and frequent intervals of rest are necessary.

I. After-image Method.

It must be remembered that these results are only approximate, and that suggestion plays a great rôle, inasmuch as after the subject says that he sees the image in a certain place once, he will always see it there.

3. Diagonal Movements.

	Up to rt.				Down to rt.				Up to lft.				Down to lft.			
	50 cm.		1 m.		50 cm.		1 m.		50 cm.		1 m.		50 cm.		1 m.	
Turning.	K.	U.	K.	U.	K.	U.	K.	U.	K.	U.	K.	U.	K.	U.	K.	U.
Average.	-5°	-5°	-10°	-6°	-3°	5°	0	-6°	10°	-5°	-5°	1.4°	5°	5°	7°	5.6°
Mean Var.	0	0	0	2°	2°	0	3°	1°	0	0	0	3°	0	0	1°	1.4°

The negative sign denotes that the image is turned down, toward the left, the positive that it is turned up, toward the right. (These results are not corrected for false torsion, due to projection on a plane surface. W. B. P.)

II. Torsion-metre Method.

The positive sign indicates torsion toward the left, and the negative sign torsion toward the right, since the subject necessarily sits facing the instrument.

My subjects in both methods are Miss Killen and Miss Udell.

This table needs little comment. It will be seen that there

is always torsion. That the amount of torsion is always approximatelythe same for the two subjects and for symmetrical positions. The mean variation is always small, within the limits of error for the instrument. It will be noticed also that there is a progressive increase in torsion with the increase in rotation, and more in the diagonal than in either the horizontal or vertical directions.

TABLE II.

Distance turned.	5°		10°		15°		20°		25°		30°	
Subject.	K	U	K	U	K	U	K	U	K	U	K	U
Direction of turn'g.												
Hor. rt.	-1.2	-1.8	-3.0	-3.0	-4.0	-5	-7.4	-7.6	-9.4	-10.0	-12.0	-11.8
m. v.	.2	.2	0.4	0.4	0.4	0.0	0.6	0.2	0.4	0.4	0.4	0.2
Hor. left.	1.6	1.6	3.4	2.8	5.2	5.2	7.6	7.8	9.8	10.2	12.2	12.0
m. v.	.2	.2	0.2	0.2	0.4	0.2	0.6	0.4	0.2	0.4	0.4	0.4
Ver. up.	1.6	1.6	3.0	3.0	5.0	5.6	7.6	8.0	9.6	10.4	11.8	12.4
m. v.	0.2	0.2	0.4	0.4	0.4	0.2	0.4	0.4	0.2	0.2	0.4	0.2
Ver. dwn.	-1.4	-1.8	-3.0	-3.0	-5.2	-4.8	-7.2	-7.8	-9.6	-9.8	-12.0	-11.8
m. v.	0.2	0.2	0.4	0.4	0.2	0.2	0.6	0.2	0.6	0.2	0.4	0.2
30° up.	-2.4	-2.8	-4.0	-4.0	-6.0	-6.6	-8.2	-9.0	-10.6	-11.4	-13.0	-13.4
m. v.	0.2	0.2	0.4	0.4	0.0	0.2	0.6	0.4	0.6	0.2	0.4	0.2
30° dwn.	2.6	2.8	4.0	4.2	6.0	5.8	8.6	8.8	10.6	10.8	12.8	12.8
m. v.	0.2	0.2	0.4	0.2	0.4	0.2	0.6	0.2	0.2	0.2	0.4	0.2
-30° up.	2.6	2.6	4.2	3.8	6.4	6.2	8.6	8.6	10.8	11.2	13.2	13.2
m. v.	0.2	0.2	0.2	0.4	0.2	0.2	0.4	0.6	0.4	0.4	0.2	0.4
-30° dwn.	-2.8	-2.6	-4.0	-4.4	-5.8	-6.0	-8.8	-8.6	-10.8	-10.6	-12.8	-12.6
m. v.	0.2	0.2	0.4	0.2	0.4	0	0.4	0.4	0.2	0.2	0.2	0.4
40° up.	-3.6	-3.6	-5.2	-5.4	-7.4	-7.0	-9.6	-9.6	-11.8	-11.6	-14.2	-13.6
m. v.	0.2	0.2	0.2	0.2	0.2	0.0	0.4	0.4	0.6	0.2	0.2	0.4
40° dwn.	3.8	3.6	5.0	4.8	6.8	7.2	9.6	9.6	11.8	12.2	13.8	14.2
m. v.	0.2	0.2	0.4	0.4	0.4	0.2	0.6	0.6	0.2	0.4	0.2	0.4
-40° up.	3.4	4.0	5.0	5.6	6.8	7.2	8.8	10.4	11.8	12.2	13.8	14.2
m. v.	0.2	0.0	0.4	0.2	0.2	0.4	0.4	0.2	0.2	0.4	0.4	0.2
-40° dwn.	-3.6	-3.8	-5.4	-5.2	-7.4	-7.0	-9.2	-10.0	-12.0	-11.4	-12.2	-13.8
m. v.	0.2	0.2	0.2	0.2	0.2	0.0	0.4	0.4	0.4	0.4	0.4	0.2
50° up.	-4.4	-4.8	-6.0	-6.2	-7.8	-8.0	-9.8	-11.0	-12.8	-12.4	-14.8	-14.8
m. v.	0.2	0.2	0.4	0.2	0.2	0.0	0.4	0.4	0.2	0.4	0.4	0.2
50° dwn.	4.4	5.0	5.4	5.6	8.4	8.2	10.2	11.4	13.0	13.2	15.2	15.2
m. v.	0.2	0.0	0.2	0.2	0.2	0.4	0.4	0.2	0.4	0.4	0.4	0.2
-50° up.	4.6	4.8	6.0	6.0	8.2	8.4	10.6	11.0	12.6	13.6	15.0	15.4
m. v.	0.2	0.2	0.4	0.4	0.4	0.2	0.6	0.4	0.2	0.2	0.4	0.2
-50° dwn.	-4.6	-4.6	-6.0	-6.2	-7.8	-8.0	-10°	-10.8	-12.4	-12.8	-15.0	-14.6
m. v.	0.2	0.2	0.4	0.2	0.2	0.0	0.6	0.2	0.4	0.2	0.4	0.2

It might be suspected that we had not secured exactly the plane of the primary position and that torsion was due to that fact. To disarm this criticism a set of experiments was made with the fixation point raised 10 cm. about 11° above the position previously used and another with the fixation point lowered the same amount. Table III shows that each position gave a greater torsion than the one chosen as primary. The vertical deviation from the primary position was then small.

TABLE III.

Horizontal rotation with plane of sight raised and lowered 11°.

		5°		10°		15°		20°		25°		30°	
		K.	U.	K.	U.	K.	U.	K.	U.	K.	U.	K.	U.
Arc raised 11°.	Right.	-2.6 0.2	-2.0 0.2	-4.4 0.2	-3.6 0.2	-6.2 0.2	-6.4 0.2	-8.4 0.4	-8.8 0.4	-10.8 0.6	-11.2 0.4	-13.4 0.2	-13.0 0.4
	Left.	2.8 0.2	2.6 0.2	3.8 0.2	4.4 0.2	6.0 0.4	5.8 0.2	8.6 0.6	8.8 0.2	10.8 0.2	10.6 0.2	13.0 0.4	12.6 0.2
Arc low'rd 11°.	Right.	-2.8 0.2	-2.6 0.2	-4.2 0.2	-3.8 0.4	-6.0 0.4	-6.0 0.4	-8.4 0.6	-8.6 0.2	-10.2 0.2	-10.8 0.2	-13.2 0.2	-13.2 0.4
	Left.	2.6 0.2	2.4 0.2	4.0 0.4	4.4 0.2	6.6 0.2	6.2 0.2	8.6 0.2	8.8 0.2	11.0 0.2	10.6 0.2	13.0 0.4	13.2 0.2

The next question that we had to answer was to determine the validity of Donder's law. We did this by measuring the amount of torsion when the same diagonal position had been reached directly from the primary position, and by a combination of horizontal and vertical movements. In each case the result of the diagonal movement was taken first, and immediately followed by the result of the vertical and horizontal movement. In nearly every instance the results coincide exactly as will be seen from the Table. Donder's Law seems to hold. There is not the slightest evidence for Listing's Law.

11. Movements to same point by diagonal and by horizontal and vertical. From 10 cm. below primary position.

(a) Diagonal	5°		10°		15°		20°		25°		30°	
	K.	U.	K.	U.	K.	U.	K.	U.	K.	U.	K.	U.
Average.	4.0°	4.0°	5.8°	5.8°	7.8°	7.4°	10.0°	10.0°	12.0	12.2°	14.6°	14.2°
Mean Var.	.4°	.0	.2°	.4°	.2°	.2°	.6°	.6°	.40	.4°	.2°	.4°

II. Movements to same point, etc.—Continued.

(b) Hor. & Ver.												
Average.	4.0°	4.0°	5.6°	5.8°	7.8°	7.2°	10.0°	10.0°	12.6°	12.2°	14.6°	14.4°
Mean Var.	.4°	0	.2°	.4°	.2°	.2°	.6°	.6°	.2°	.4°	.2°	.4°

SUMMARY.

1. It is evident that there is a contradiction between Listing's and Donder's laws for torsion in eye movement.

2. Experiments by the after-image method seemed to confirm Listing's law. But there are two sources of error—inaccuracies in measurement, and false torsion, due to projection on a plane surface, which it is difficult to make allowances for.

3. More accurate direct measurements show that there is always torsion with rotation, and the amount of torsion is proportional to the amount of rotation.

4. Donder's law holds. The eye has the same amount of torsion in each position whether that position be reached by direct movemement from the primary position or by two successive movements.